Will Data Assimilation Techniques Open a New Frontier for Aeronomy?

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Removal of a Myth!

A commonly held view is expressed as *"Since Aeronomy Science has been around for a long time, there is nothing new to learn about Aeronomy."*

Rubbish, and one not held by us!!!

- We know about as much about Aeronomy as we do about an ***iceberg***, i.e., =10%. (Who knows how to visualize the 90% of the iceberg under the water?)
- It's the 90% of the ***iceberg*** we don't know about that would sink oil rigs off Newfoundland.
- It's the 90% of Aeronomy, the weather, that is geoeffective.

So What is the Problem With our Knowledge of Aeronomy?

The local physics and chemistry are well known? (ah! The Burnside factor, the thermospheric cooling coefficients, . . .)

- but will data assimilation help?

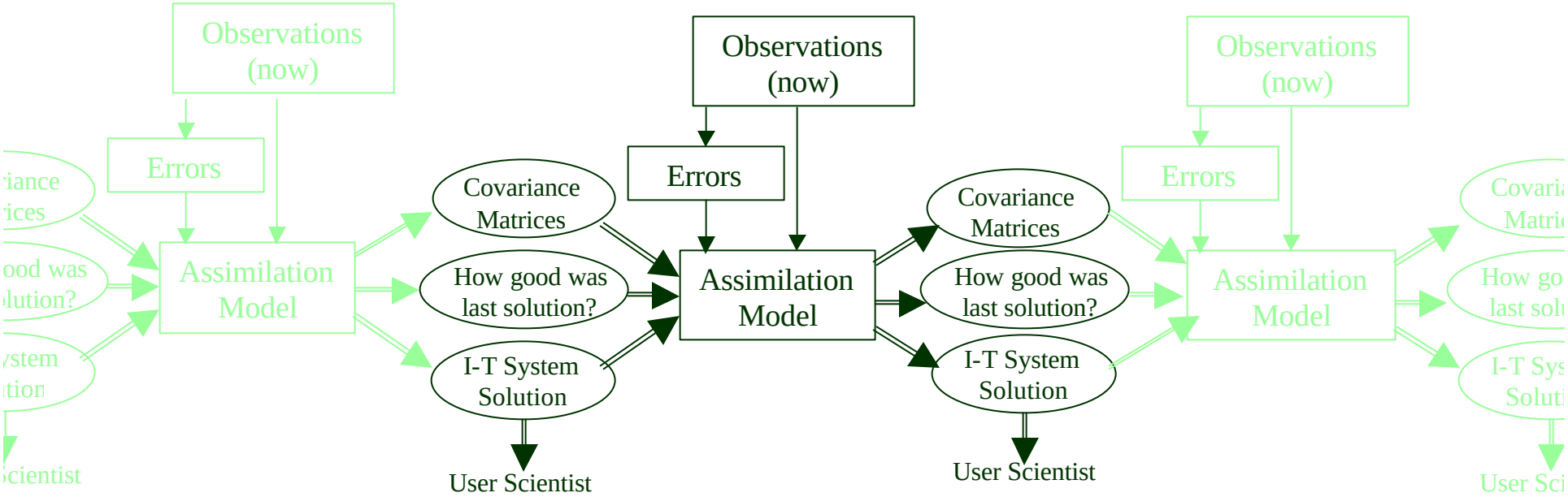
The ionosphere and thermosphere physics and chemistry are known to have different spatial and temporal scales. (ah! Rate of energy transfer between I-T depends on scale; do we know the effective scales?)

- but will data assimilation help?

The coupled ionosphere and thermosphere are well understood to the point that we have global and regional models of each. (ah! But a huge set of constraints on boundary conditions and external drives are needed; we don't have them?)

- but will data assimilation help?

How Does Data Assimilation Work?



Time Stepping Forward

The Assimilation "Box"

Inputs

New Observations + Observational Errors
Prior "State Vector" Solution + Uncertainty
Prior "Covariance" Matrices

Internal

Simultaneously:

(a) Predict New Solution
(b) Compare with Observations
(c) Weighted Least-Squares Fit
(d) Re-evaluate Covariance Matrices
(e) Correct Prediction
(f) Determine Solution Error

Output

New "State Vector" Solution + Uncertainty
New "Covariance" Matrices

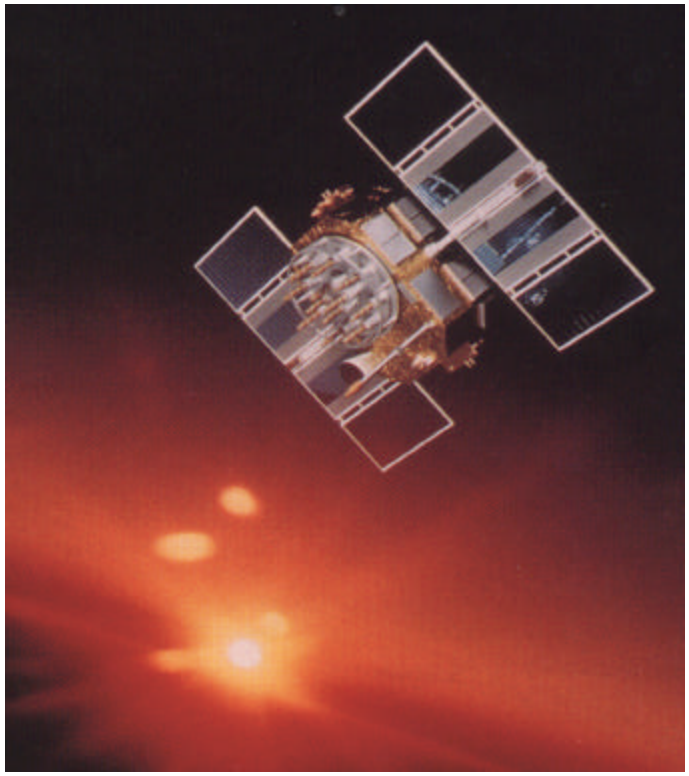
What Does Data Assimilation Offer Aeronomy?

- Each time step gives a New Solution for the State Vector.
  - - - - AMIE creates maps of the ionospheric electric field and current systems.
  - - - - JPL-GIM creates maps of the ionospheric TEC.
  - - - - GAIM produces 3-D density distribution.
- Each time step gives the uncertainty of each element in the State Vector.
  - - - - Under used to date.
- Each time step gives the goodness of fit, i.e., how well the "Physics" in the assimilator is reproducing the observations.
  - - - - Under used to date.

But, also --

- The solution “State Vector” can contain scaling factor and biases, in addition to the usual state variables of the thermosphere and ionosphere.
- The USU-GAIM data assimilation models use vast amounts of ground based GPS. Although satellite bias is known, ground receivers all have independent “constant” biases. Hence, each station’s TEC bias is an element in the State Vector.
- Could the Burnside factor ever be treated as an element of the State Vector?

Probably Yes



GPS satellites transmit at two ‘L’ band frequencies. A ground receiver can sync on these signals and TEC can be inferred.

→ There are over 1000 GPS TEC receivers collecting data.

→ It is not humanly possible for business as usual scientific analysis to be done to give justice to this data stream!

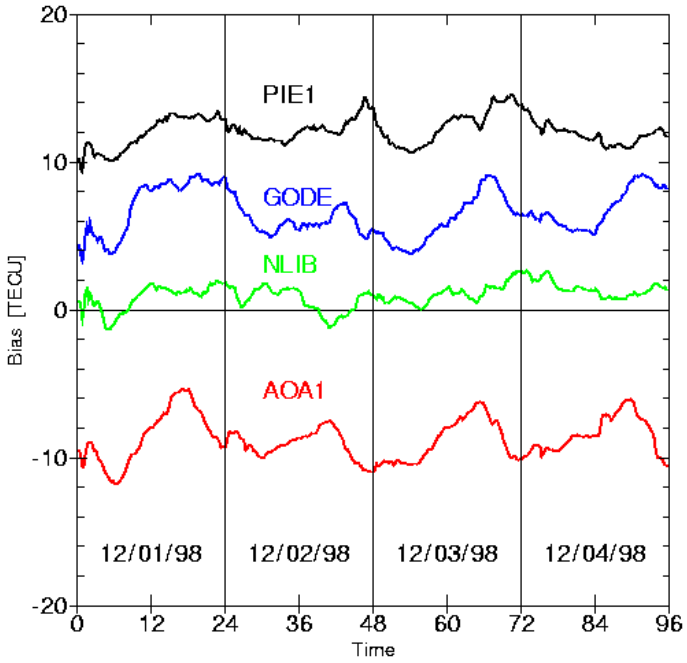
→ There are 1000’s of unknown ground receiver biases.

The JPL-GIM and GAIM models assimilate between 30 and 150 GPS receivers’ data streams.

They produce ionospheric representations

Furthermore,

they simultaneously deduce the receiver biases and uncertainty.



Swamped with Data!

Ionosphere

- GPS is but one example where data availability exceeds the capability of conversion scientific method to cope.
- COSMIC will generate many 1000's of GPS TEC occultations per day.
- How do you combine these integral N_e measurements with in situ N_e measurements?

Thermosphere

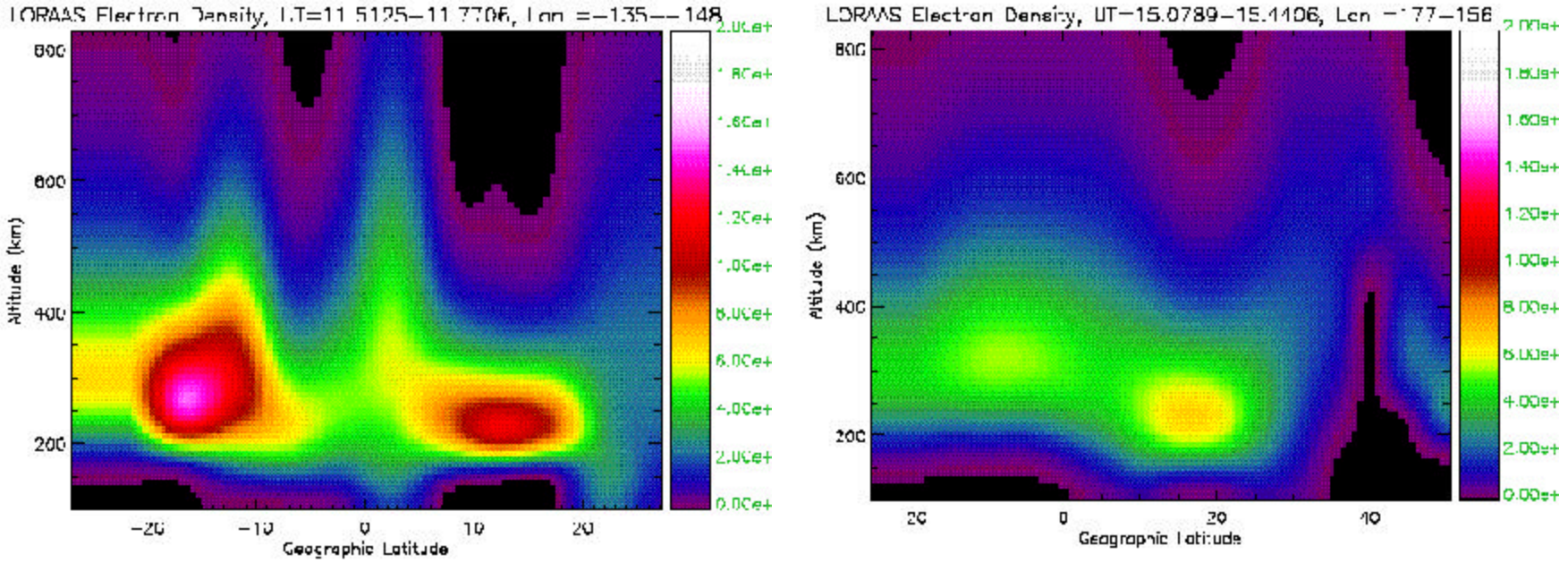
- The thermosphere has been relatively unbounded, but this is changing.
- UV sensors on DMSP and future weather satellites will provide vast numbers of line-of-sight observations at multiple wavelengths.
- These UV line-of-sight data will have new analysis challenges and for a "first-time" provide detailed weather variability in the thermosphere on scales sufficient to constrain our models and understanding.

LORAAS: a UV Milestone

- The US Navy ARGOS satellite flew a prototype future DMSP UV instrument called LORAAS.
- Through sophisticated data reconstruction (tomography and aeronomy), slices of the ionosphere are created.
- Prior to these views, only MODELS could generate them.
- Need huge scale data assimilation to handle these.
- Other wavelengths allow the thermosphere to be reconstructed.

P.S. The Navy might not know what an iceberg looks like, but they do see the ionosphere and thermosphere.

Aeronomy from ARGOS Satellite LORAAS Observations



Provided by Stefan Thonnard and Sarah McDonald (NRL)

A New Generation of Aeronomers

– Present Day Aeronomy –

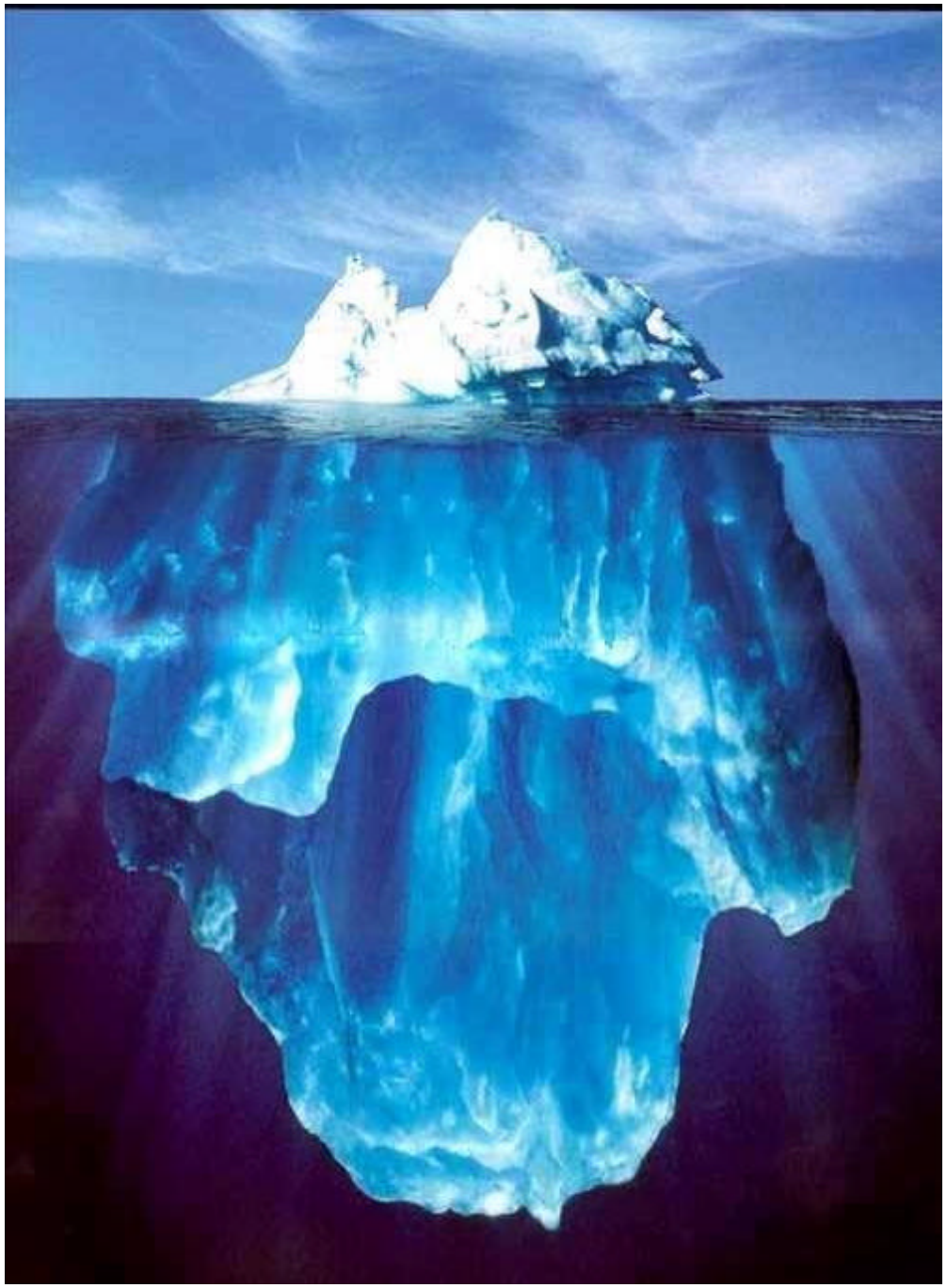
- Our science discipline is heavily based on dedicated complementary experts: experimenters, theorists, modelers, and laboratory types.

– Future Aeronomy –

- Data Assimilation is a new category in this list.
- As a community, we need to create these new “assimilators;” a new generation of graduate students and postdocs are needed.
- Need to develop expertise in:
  - Instrument output ***and error***.
  - Physics of the I-T system ***and uncertainty***.
  - Mathematics of advanced least-squares fitting (KALMAN)
  - High performance computing techniques.
- Be a pioneer because everyone will tell you it’s a “fad” that will go away.

What Will the New Generation of Aeronomers Generate?

- Produce an evolving solution for whichever aspect of an aeronomy system is being studied with:
  - Error bars on all solution parameters
  - Quantification of how well the propagation model (Physics) and the observations are converging.
- Develop assimilation schemes to determine values, and their uncertainties, for basic aeronomy rate coefficients and processes.
- Get the maximum scientific return out of the huge GPS-TEC, DMSP-UV, etc., data streams.



I can’t give you the 90% Aeronomy Picture, but here is the rest of the ICEBERG.

Thanks to a Rig Manager for Globan Marine Drilling in St. Johns, Newfoundland. A commercial diver protecting oil rigs near Newfoundland from these monsters found conditions perfect for this shot, with the sun almost directly overhead and the water calm and clear.